A Commercial Laboratory Soft-X-ray Source for Water Window Microscopy

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ABSTRACT

Beginning in 2006, Energetiq Technology Inc. began development[1] of a soft x-ray source based on our commercially successful EUV source[2], based on a unique electrode-less Z-pinch design. Operating in Nitrogen, the source produces up to 400 mW of radiation at 2.88 nm. (430 eV)[3]. The source has been used as an illuminator for our own demonstration water-window microscope, and has been successfully integrated by Xradia, Inc. (Pleasanton, CA, USA) with their cryo-tomo-capable soft x-ray microscope, the UltraXRM-S/L220c. While laboratory demonstrations of microscopes driven by table-top x-ray sources have been done [4, for instance], this is the first commercially available instrument of this type. We will present detailed performance data for the source.

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2005: First EQ-10; 10 W/2pi, 13.5 nm [1]

EQ-10 Concepts..

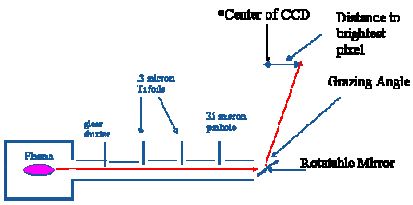
10 watts/2p, 13.5 nm, +/- 1% bandwidth.

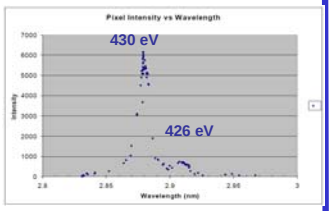
Xenon plasma. (Xe 10+)

Source developed (2005) to enable EUV lithography for semiconductor fabrication.

Further developments: [2,3]

2006: Phase 1 – explore various gases; power and spectral measurements.

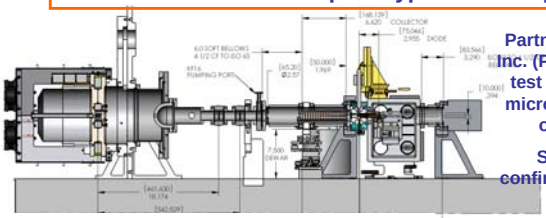




•Diagnostics developed. Several gasses tested; nitrogen selected: 430 eV from N5+. $\Delta\lambda/\lambda < 1/500$ Helium-like transition

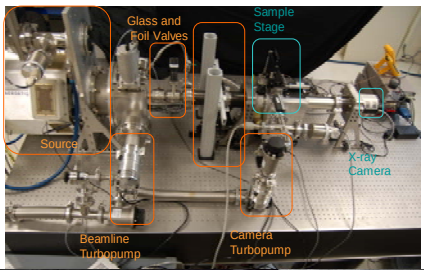
•Plasma volume increased – compensate for molecular losses compared to Xenon. First power measurements ~ 200 mW/2π

2007-2009 : Phase 2 - prototype microscope [4]

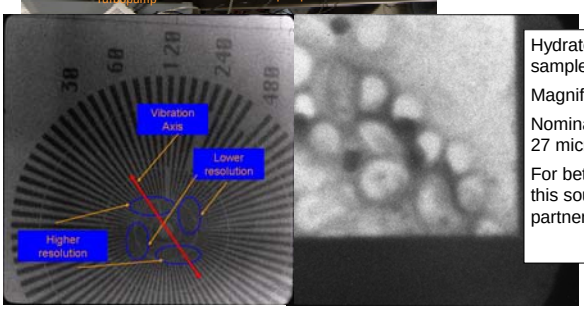


Partnered with Xradia, Inc. (Pleasanton, CA) to test on a commercial microscope as well as our prototype.

Spectral purity confirmed adequate via imaging



Since zone plate focal length varies with wavelength, line bandwidth can cause chromatic aberration. Resolution limits due to line bandwidth have not been seen. Resolution limit is better than 30 nm. (See Xradia results, this meeting.)



Hydrated yeast sample (not frozen).

Magnification 484x

Nominal field of view 27 microns

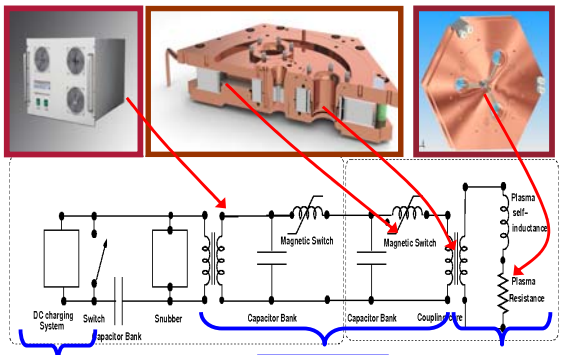
For better photos with this source, see our partner, Xradia.

Ultimately, resolution was limited by drift and vibration. Achieved ~ 50 nm resolution on our microscope; ~ 40 nm resolution at Xradia.

2010-2011 Phase 2 Renewal: Cryo-Tomo results, Extensive testing, lifetime and maintanance improvements.

- **Power system rebuilt - increased pulse energy, pulse rate**
- **Architectural modifications to manage higher voltage**

Simplified schematic diagram of power system and source.

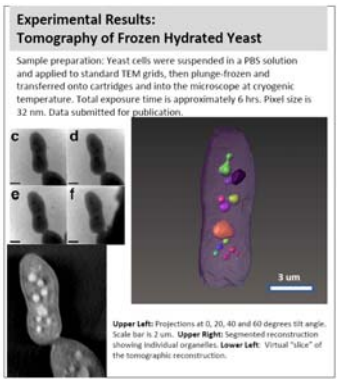


Drive

Nonlinear transmission line

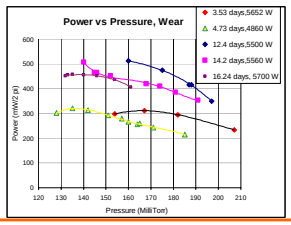
Nonlinear, unmatched load

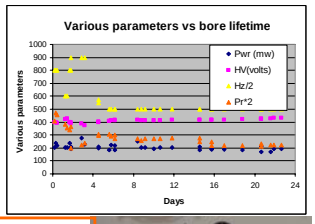
2010: Cryo-tomography at Xradia



- **First cryo-tomographic results.**
- **Major effort to improve bore lifetime.**
- **Lifetime improved from ~ 5 days to ~ 20 days, at higher output power.**
- **Maintanance time (bore change, power to power) reduced from ~ 3 days to ~ 12 hrs**

Power output to 400 mW; 20 day bore life achieved





2012: Installation at customer site (DiamondLight Source , UK)

Acceptance testing onsite prior to connecting source to microscope

References

[1] Denbeaux, G., Naulleau, P., Horne, R. G. S., Besen, M., First use of the Energetiq 10w Electrodeless Euv Plasma source. In: 2005 International EUVL Symposium, San Diego, CA.

[2] Horne, S. F., Niell, F. M., Partlow, M. J., Besen, M. M., Smith, D. K., Blackborow, P. A., Gustafson, D., 2009. Development of a high-pulse-rate euv source. Vol. 7271. SPIE, pp. 72713A+

[3]M. Partlow, M. Besen, P. Blackborow, R. Collins, D. Gustafson, S. Horne, and D. Smith, "Extreme-ultraviolet light source development to enable pre-production mask inspection (journal paper)," 2012.

[4]S. F. Horne, J. Silterra, and W. Holber, "A compact soft x-ray microscope using an electrode-less z-pinch source," Journal of Physics: Conference Series, vol. 186, no. 1, pp. 012 028+, 2009. [Online]. Available: http://dx.doi.org/10.1088/1742-6596/186/1/012028